N89-12882

FATIGUE AND FRACTURE OVERVIEW

Gary R. Halford
NASA Lewis Research Center
Cleveland, Ohio

The programs in the fatigue and fracture area of the HOST Project have developed to the point that we can now refer to accomplishments rather than goals. This has necessitated a change from the overview format that I've used in the past couple of years. This year, for each program, I will briefly discuss the major accomplishments, the on-going work, and any that remains for the future. A list of the programs currently supported under fatigue and fracture is shown in table I. There are three contract programs, one grant, and an in-house activity. As I look back over the past few years, it is gratifying to see the advances that have been achieved. Indeed, we now know more about how to design for greater durability, and we are better equipped with analysis tools and hardware for performing durability studies - these advances will be noted as accomplishments. We are also in our prime performance period, during which advances come more easily than before - these advances will be mentioned as on-going work, and greater detail will be provided by the individual presenters. Finally, numerous tasks remain to be accomplished in the future.

Figure 1 summarizes the accomplishments achieved under the isotropic creep-fatigue crack initiation life prediction program. This program was handled by Pratt & Whitney under contract NAS3-23288. Dr. Vito Moreno was the original project manager, and Mr. Richard Nelson took over about 2 years ago. To date, a sizeable creep-fatigue crack initiation data base has been generated on the nickel-base superalloy, B-1900. Companion constitutive modeling programs have also generated extensive data bases on the same heat of material. The crack initiation results have formed the basis of a new approach to creep-fatigue life prediction. The term CDA (Cyclic Damage Accumulation) has been coined for the method, which has been evaluated under isothermal, uniaxial conditions. Stringent laboratory verification experiments have been used to test the accuracy of the method. Considering the quite limited material property data needed to evaluate the constants in the approach, the prediction accuracy is acceptable. At the expense of the larger data base required, the Lewis developed total strain - strainrange partitioning method (TS-SRP) is capable of a higher degree of accuracy. Details of both the CDA and the TS-SRP methods can be found in reference 1.

The current work will be described in greater depth in the Fatigue and Fracture Session by Mr. Nelson. Suffice it to say here that the work is concentrating on the development of modules to account for multiaxial loading, complex loading histories (i.e., cumulative fatigue damage) and thermomechanical loading. Color graphics (fig. 2) of the temperature and stress and strain distributions are quite revealing to the designer in pinpointing hot spots and concentrations of potential damage.

Future activities under the contract call for the development of modules to deal with environmental attack, protective coatings, and mean stress (fig. 3). These modules will be integrated into the master life-prediction model, and laboratory verification of the completed model will be achieved through use of an alternative alloy. Inco 718 will be used for verification purposes.

The isotropic high-temperature crack growth program at the General Electric Company, under the direction of Dr. J.H. Laflen, has reached a couple of significant milestones. Following a great deal of analysis and experimentation, a satisfactory crack-growth specimen geometry has been selected (fig. 4) that can provide the reliable cyclic growth results needed in the program. Also, numerous so-called path-independent integrals J(x) have been screened to determine their applicability to high-temperature crack propagation problems. Three approaches have been shown to adequately capture the stress intensity around a loaded crack in a thermal gradient field (fig. 5). Greater detail of the path-independent integral approach for high-temperature crack growth will be presented by General Electric in the Fatigue and Fracture Session. Future work will concentrate on finalizing the cyclic crack growth computer code and on verifying the code through use of an alternate material/specimen geometry.

Figure 6 summarizes the major accomplishments under the anisotropic cyclic crack initiation and constitutive modeling program of Pratt & Whitney under the direction of Mr. Gus Swanson. Work has concentrated on developing the cyclic constitutive model applicable to material response before crack initiation. A workable single-crystal constitutive model has been developed and integrated into a computer code. Based on the classical Schmid law for critical resolved shear stress and upon the unified constitutive modeling theory of Dr. Kevin Walker, the anisotropic constitutive model has proven itself to be powerful tool for the analysis of high-temperature components such as turbine blades. Verification of the model has been achieved at the laboratory specimen level. A composite computer-generated plot of a cyclic stress-strain hysteresis loop of single crystal PWA 1480 and of its PWA 286 overlay coating is shown in figure 6. Note the nominally elastic response of the PWA 1480 and the elasto-plastic-creep response of the much weaker, ductile coating.

Currently, the crack initiation data base is being generated upon which the life-prediction method will be built. Both isothermal low-cycle fatigue and thermomechanical fatigue experiments are being conducted. Results are also being collected on the behavior of PWA 273, an aluminide coating. Preliminary evaluations of existing life-prediction methods are being made. Some of the complexities of this task are illustrated by the sketch in figure 7.

The root attachment area of single-crystal turbine blades (fig. 8) poses additional complexities that are to be addressed later in the program. As a final note, the life models for the root attachment area and the higher-temperature airfoil region will have to be integrated into a single life-prediction that can be interfaced with the cyclic constitutive modeling programs for an overall analysis of gas turbine blades.

Figure 8 illustrates the significant accomplishments of the basic research grant with Prof. H.W. Liu at Syracuse University. From a phenomenological viewpoint, he has developed a parameter, based on ΔJ, that accurately describes fatigue crack growth under large-scale plastic yielding. An indication of the predictive capabilities is given in figure 9. Seven different alloys are included, and the normalized growth rates cover four orders of magnitude. Details of this room temperature work are contained in reference 2. In his attempts to gain a better understanding of the micromechanisms of cyclic crack growth at elevated temperatures, he has proposed a model based on the oxidation kinetics at the growing crack tip. The model provides for a transistion between the time-independent plasticity-induced crack growth and the time-dependent oxidation-governed growth. More detail will be provided by Prof. Liu in his presentation in the Fatigue and Fracture Session. Work is continuing on modeling of the micromechanisms of crystallographic slip at the tip of a growing crack. The effort is directed at the so-called small crack problem, and, to make the problem easier to address experimentally, specimens with extremely large grain sizes have been manufactured. A typical specimen is shown in figure 10 wherein only two or three grain boundaries are encountered as the crack grows across the specimen.

Lewis' in-house effort focused principally on the refurbishment of the high-temperature fatigue and structures laboratory. This facility is now operational and growing daily. To date, we have been able to add seven new closed-loop, servo-controlled cyclic testing machines, each of which is capable of being interfaced with dedicated satellite minicomputers which, in turn, communicate with the master computer in the centralized control room. A view of part of the new control room is shown in figure 11. Experiments are now being performed on a routine basis that just could not have been attempted a couple of years ago. Our computer-aided capabilities are constantly growing as the available software continues to expand. Over the new few years, we expect to be generating valuable theory verification using the multiaxial, thermomechanical, and cumulative damage test equipment that is now coming on-line.

In summary, I would like to emphasize the significant progress that has been achieved in the fatigue and fracture arena through the atmosphere created by the HOST Project. Unquestionably, we are now better prepared than ever before to deal with durability enhancement in the aeronautical propulsion industry through theoretical, analystical, and experimental approaches. Given the opportunity to complete the tasks we have started, we expect to reap even greater rewards over the next year or two.

REFERENCES

1. Moreno, V.; Nissley, D.M.; Halford, G.R.; and Saltsman, J.F.: Application of Two Creep Fatigue Life Models of the Prediction of Elevated Temperature Crack Initiation of a Nickel Base Alloy. Presented at the AIAA/SAE/ASME/ASEE 21st Joint Propulsion Conference, Monterey, Calif., July 8-10, 1985. Preprint No.

2. Minzhong, Z and Liu, H.W.: Crack Tip Field and Fatigue Crack Growth in General Yielding and Low Cycle Fatigue. (Syracuse University, NASA Grant NAG3-348), NASA CR-174686, Sept. 1984.

TABLE I

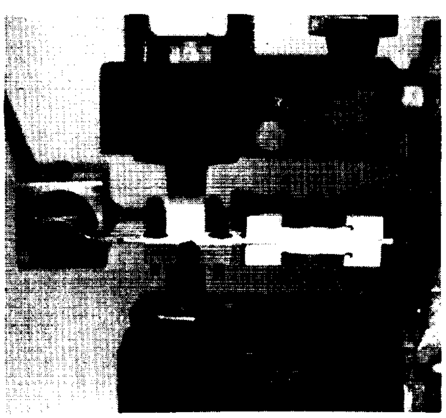
FATIGUE AND FRACTURE PROGRAMS

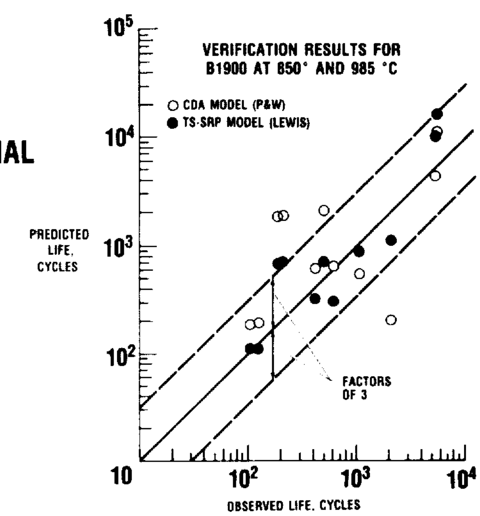
- NAS3-23288, PRATT & WHITNEY (R.S. NELSON), LEWIS (G.R. HALFORD)
  CREEP-FATIGUE CRACK INITIATION—ISOTROPIC
- NAS3-23940, GENERAL ELECTRIC (J.H. LAFLEN), LEWIS (T.W. ORANGE)
  ELEVATED TEMPERATURE CRACK GROWTH—ISOTROPIC
- NAS3-23939, PRATT & WHITNEY (G.A. SWANSON), LEWIS (R.C. BILL)
  LIFE PREDICTION/CONSTITUTIVE MODELING—ANISOTROPIC
- NAG3-348, SYRACUSE UNIVERSITY (H.W. LIU), LEWIS (I.J. TELESMAN)
  CRACK GROWTH MECHANISMS—ISOTROPIC
- LEWIS,(M.A. McGAW)
  HIGH-TEMPERATURE FATIGUE AND STRUCTURES LABORATORY

CD-86-21861

CREEP-FATIGUE CRACK INITIATION—ISOTROPIC ACCOMPLISHMENTS

- LARGE DATA BASE
- CDA MODEL-P&W
- TS-SRP MODEL-LEWIS
- MODELS VERIFIED-ISOTHERMAL





CD-86-21867

Figure 1

ORIGINAL PAGE IS
OF POOR QUALITY

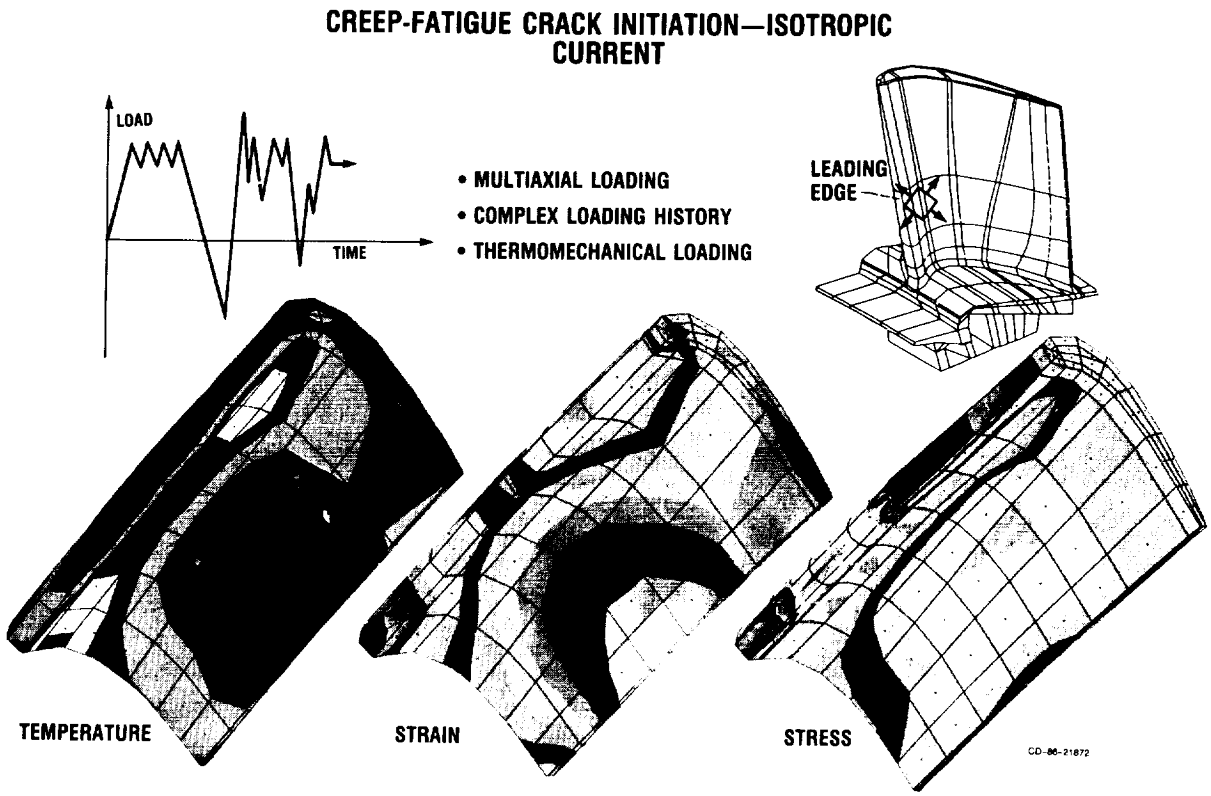
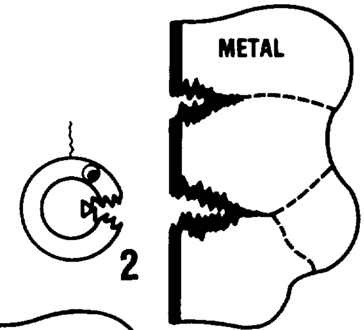


Figure 2

CREEP-FATIGUE CRACK INITIATION—ISOTROPIC FUTURE

- ENVIRONMENTAL MODULE
- COATINGS MODULE
- MEAN STRESS MODULE
- MODULES INTEGRATED INTO MODEL
- ALTERNATIVE ALLOY VERIFICATION



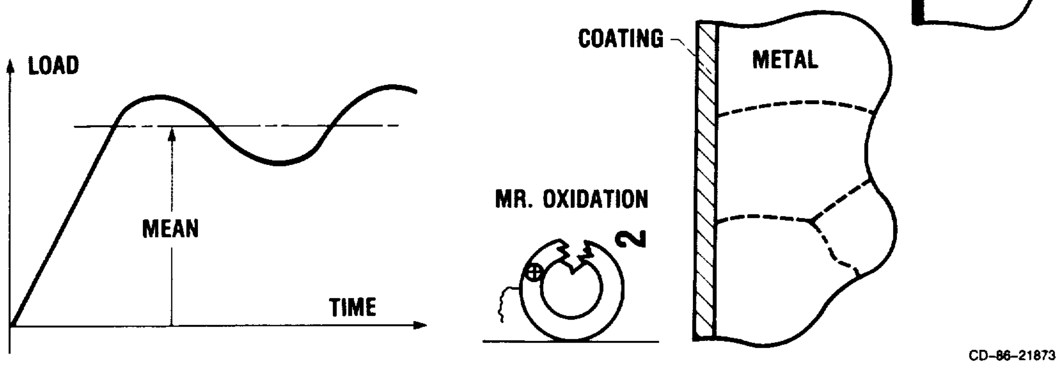
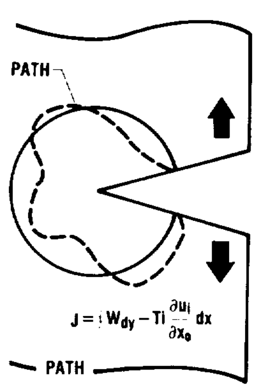


Figure 3

CRACK GROWTH—ISOTROPIC ACCOMPLISHMENTS

- DEVELOPED STANDARDIZED CRACK GROWTH SPECIMEN
- PATH-INDEPENDENT INTEGRALS (J_x) IDENTIFIED



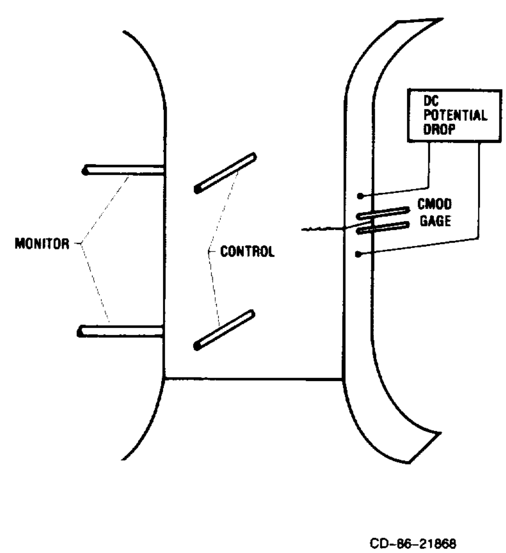


Figure 4

CRACK GROWTH—ISOTROPIC
CURRENT

- ISOTHERMAL VERIFICATION
- NONISOTHERMAL VERIFICATION

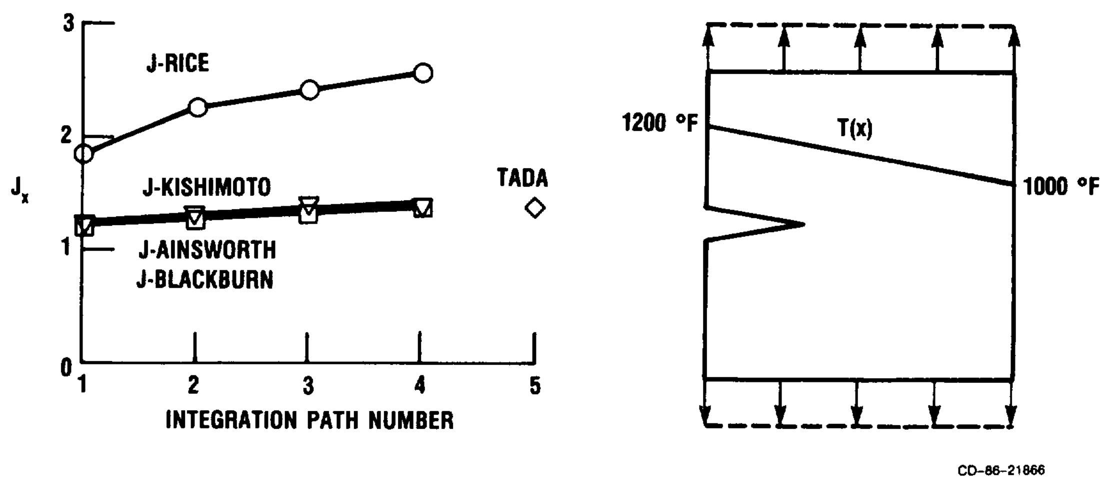


Figure 5

INITIATION AND CONSTITUTIVE MODELING—ANISOTROPIC
ACCOMPLISHMENTS

- SINGLE-CRYSTAL CONSTITUTIVE MODEL (PWA 1480)
  - SCHMID LAW
  - WALKER THEORY
- OVERLAY COATING CONSTITUTIVE MODEL (PWA 286)
  - WALKER THEORY

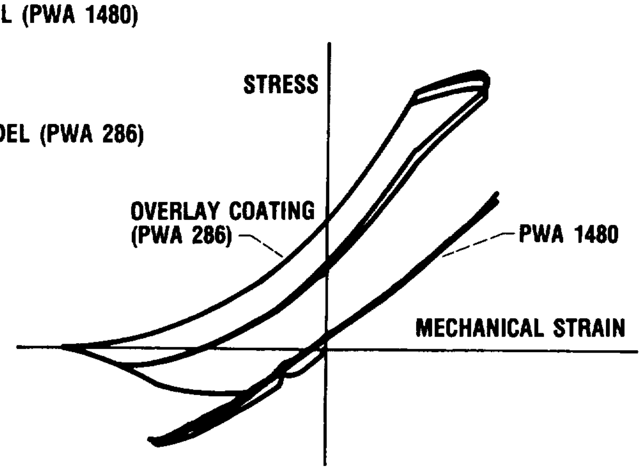


Figure 6

INITIATION AND CONSTITUTIVE MODELING—ANISOTROPIC CURRENT

- LCF/TMF DATA BASE (COATED PWA 1480)
- ALUMINIDE COATING DATA BASE (PWA 273)
- PRELIMINARY LIFE MODELS

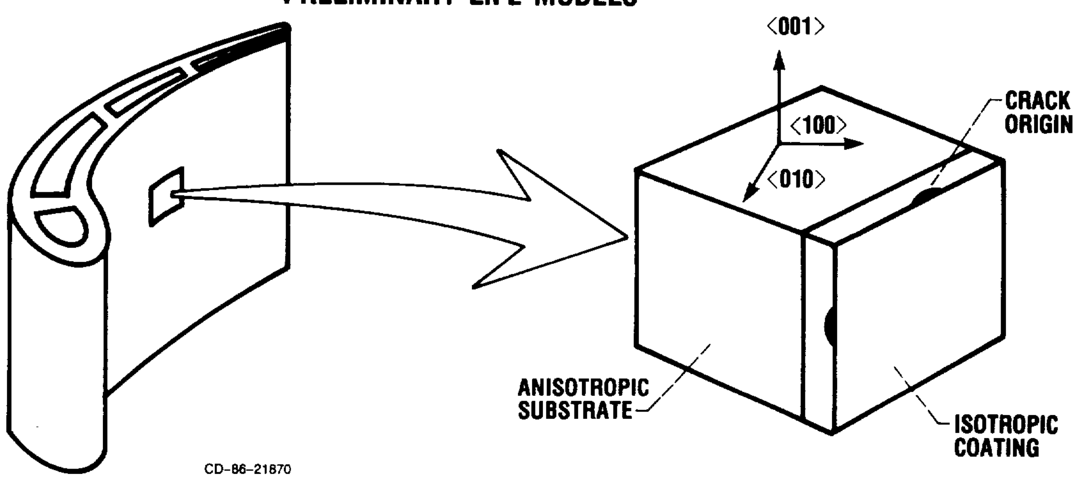


Figure 7

INITIATION AND CONSTITUTIVE MODELING—ANISOTROPIC FUTURE

- BLADE ATTACHMENT
- INTEGRATED LIFE MODELS

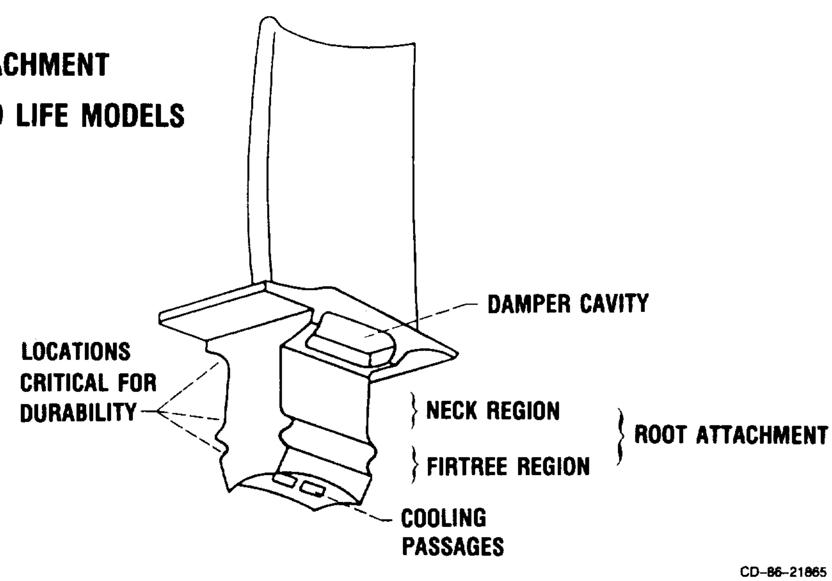
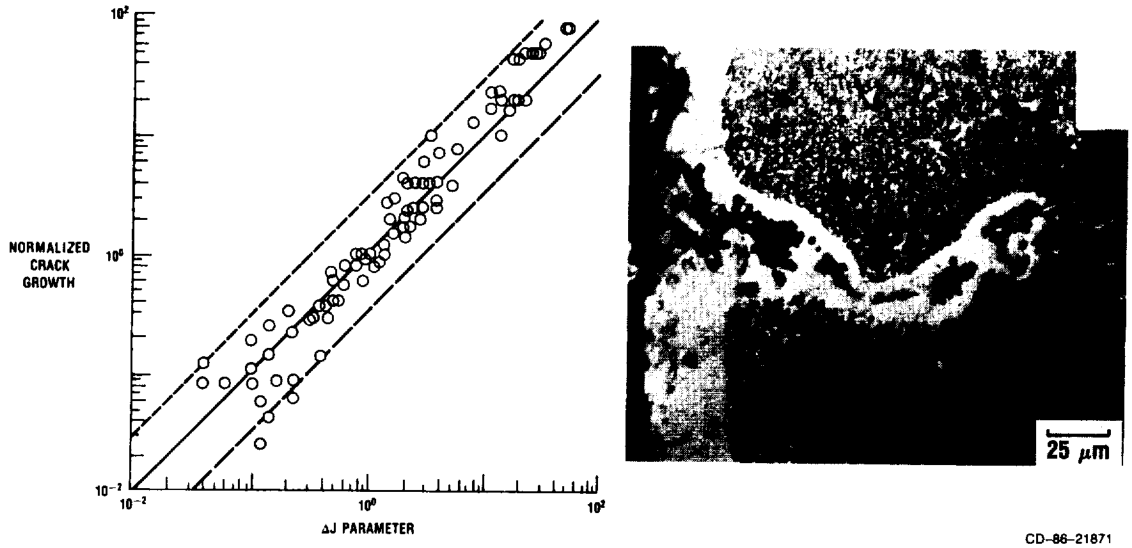


Figure 8

CRACK GROWTH MECHANISMS—ISOTROPIC ACCOMPLISHMENTS

- ΔJ PARAMETER FOR LOW TEMPERATURE da/dN
- OXIDATION MODEL FOR HIGH TEMPERATURE da/dN



CD-86-21871

Figure 9

CRACK GROWTH MECHANISMS—ISOTROPIC CURRENT/FUTURE

- CRYSTALLOGRAPHIC MODEL OF da/dN

CD-86-21863

Figure 10

ORIGINAL PAGE IS
OF POOR QUALITY

HIGH-TEMPERATURE FATIGUE AND STRUCTURES LABORATORY ACCOMPLISHMENTS

- INTEGRATED/AUTOMATED MATERIALS TESTING CAPABILITY
  - SEVEN NEW CLOSED-LOOP MACHINES
  - ONE HOST COMPUTER
  - 16 SATELLITE MINICOMPUTERS

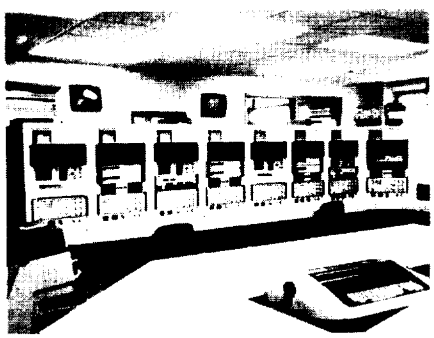


Figure 11

CD-86-21859